NASA TECHNICAL NOTE

NASA TN D-2775

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FLIGHT INVESTIGATION OF STEEP INSTRUMENT APPROACH CAPABILITIES OF A T-33 AIRPLANE UNDER MANUAL CONTROL

by Albert W. Hall and Donald J. McGinley, Jr.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1965

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FLIGHT INVESTIGATION OF STEEP INSTRUMENT APPROACH CAPABILITIES OF A T-33 AIRPLANE UNDER MANUAL CONTROL

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SUMMARY

A flight investigation has been conducted to determine the steep instrument approach capabilities and limitations of a T-33 airplane under manual control. The study included an investigation of flare paths suitable for transition from the steep glide slope to touchdown.

The maximum glide slope feasible for operational use in an instrument approach was 6°. This limit was established by the desired approach speed and the minimum engine speed that could be used. The minimum engine speed was chosen as the lowest speed which would still respond adequately if a wave-off occurred.

More pilot effort was required to fly the 6° glide slopes than the 2.5° slopes.

The greatest problem during the instrument approach and flare was the effort required to maintain proper lateral-directional control. Simulated autopilot lateral-directional control was found to be very effective in allowing more effort to be put on the glide-path control, which resulted in consistent touchdowns with the pilot under the hood.

Flare paths which required about 25 to 30 seconds for transition from the 6° glide slope to the terminal angle were found to be satisfactory for manual control under instrument flight.

INTRODUCTION

In making the normal instrument approach (2.5° to 3° glide slope), the current turbojet transports use a large amount of airspace. In addition, the engines of these transports produce noise of an objectionable level when the long, low instrument approach takes the turbojets over populated areas. According to reference 1, the most frequent public complaints today are concerned with the approach noise rather than the take-off noise. Some recent studies have indicated that the landing-approach engine noise of the supersonic transport is expected to be even more severe than that of the current turbojets. One method of reducing both the airspace requirements and the ground noise level would be to steepen the approach glide slope. Since little or no flight-test data are available, an investigation was undertaken on several different types of aircraft to determine how aircraft characteristics influence steep-approach capabilities.

The first aircraft investigated was a twin-engine, transport-type, propeller-driven airplane (C-47). The results of that investigation are reported in reference 2. The results of a similar investigation on a single-engine, straight-wing, two-place jet trainer are presented herein.

EQUIPMENT

Guidance

Glide slope and flare.- Glide-slope and flare guidance was provided by a biangular system previously described in references 2 and 3. This system consisted of two ground-based transmitters (glide slope and flare), two airborne receivers (one for each transmitter), and an airborne flare-path computer. Each transmitter sent out coded signals which were received in the aircraft and decoded to give the elevation angle of the airplane relative to the particular transmitter. Elevation angles up to 20° could be measured.

The geometry of the guidance system is illustrated in figure 1. The rearward (flare) transmitter was located 3000 feet down a 10 000-foot runway at

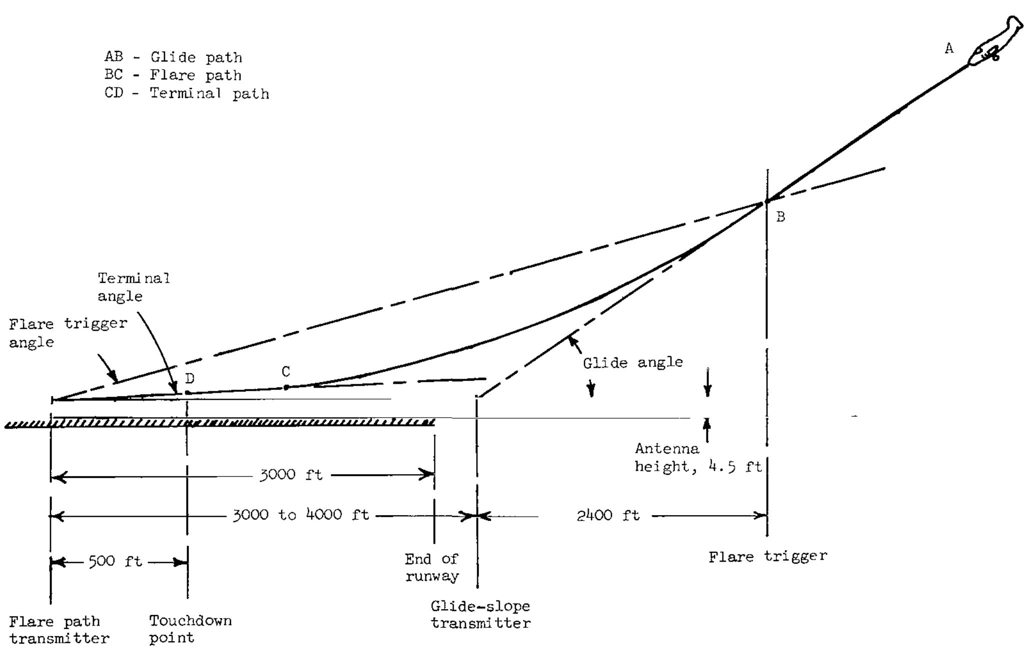


Figure 1.- Biangular guidance system.

Langley Air Force Base, Virginia and about 300 feet to the right of the runway center line. The forward (glide-slope) transmitter was located near the approach end of the runway for some of the tests and 1000 feet ahead for other tests giving a distance of 3000 and 4000 feet between sites. As shown in the figure, the forward transmitter provided glide-slope guidance (A to B) and the rearward transmitter provided flare-path guidance (B to C) and terminal-angle guidance to touchdown (C to D).

A detailed description of the flare-path guidance has been given in reference 2. The flare initiation, or flare trigger point, was located 2400 feet ahead of the glide-slope origin for all the glide-slope angles used in this investigation. This geometry gave a nominal altitude at the beginning of the flare of 105 feet, 252 feet, and 376 feet for glide slopes of 2.5°, 6°, and 9°, respectively. The flare paths provided guidance to direct the airplane along a smooth path, gently curving away from the glide slope to a final terminal slope of about 0.5°. The transmitter and receiver antenna heights were related so that when the airplane was flying along the terminal angle, the wheels would touch down about 500 feet ahead of the flare transmitter site.

Directional guidance.- The guidance for the horizontal plane was provided by the localizer used in the instrument landing system (ILS) at Langley Air Force Base. This localizer provided an angular deviation system with the origin 1500 feet beyond the runway on the extended center line (11 500 feet from the approach end of the runway).

Guidance display.- Deviations from the desired flight path were displayed to the pilot on an ILS cross-pointer indicator which showed flight-path deviations in angular units as is standard in present-day ILS. Full-scale deflection of the horizontal cross pointer (glide-slope needle) represented a deviation of $\pm 0.6^{\circ}$ from the flight path as measured at the forward transmitter for the glide slope and at the rearward transmitter for the flare. A given cross-pointer deflection, therefore, represents an increasing sensitivity or a decreasing distance from the desired path as the transmitter is approached.

Full-scale deflection of the vertical cross pointer (localizer needle) represented a deviation of $\pm 2.5^{\circ}$ from the desired directional path as measured from a point 11 500 feet from the approach end of the runway.

Airplane and Instrumentation

A drawing of the T-33 airplane used in this investigation is shown in figure 2. The approaches were made with the speed brakes out and the gear down; half-flaps were used for the 2.5° glide slopes and full-flaps were used for the steeper glide slopes. The airplane wing loading varied between 55 and 42 pounds per square foot as fuel was consumed.

The airplane was instrumented with standard NASA flight-test instrumentation to measure and record the following quantities: airspeed, pressure-altitude, throttle position, flap position, elevator position, deviation of glide-slope needle, deviation of localizer needle, angle measured by glide-slope

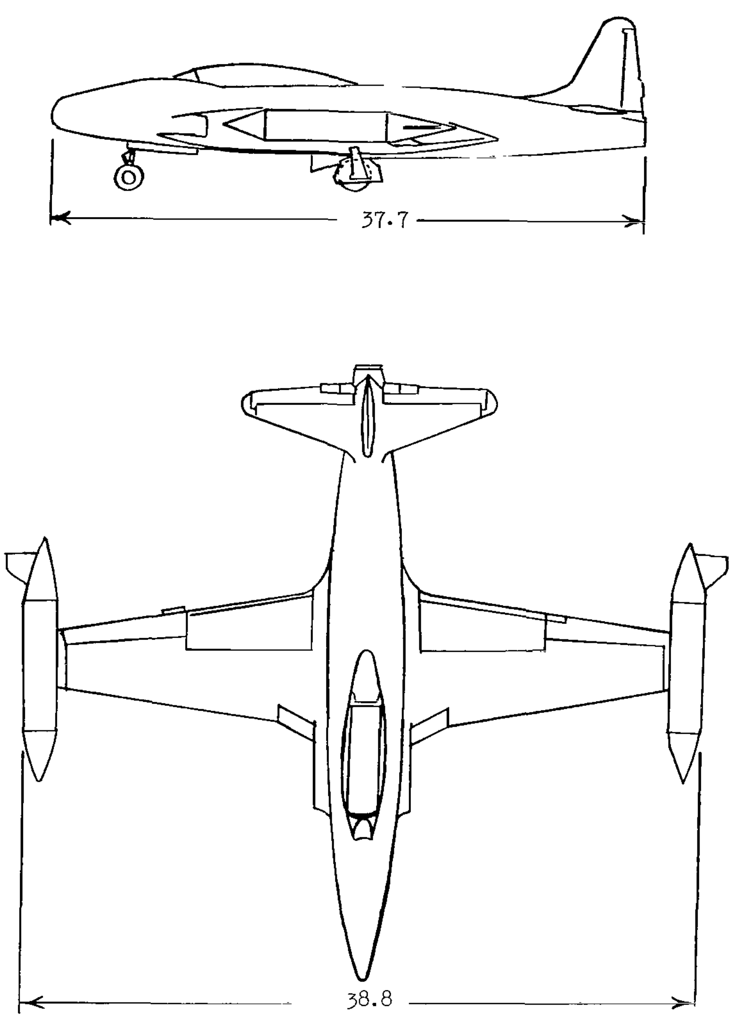


Figure 2.- Airplane used in investigation.
Dimensions are in feet.

receiver, and angle measured by flare receiver. All recording instruments were correlated by an NASA timer. In addition to normal cockpit instrumentation, two angle indicators were included to display the glide-slope and flare angles and a panel light was installed to indicate the flare trigger.

TESTS

Pilots

The pilots participating in this program were NASA experimental test pilots with varying degrees of experience ranging from over 20 years to a few years of flight-test work. Although these pilots have not had the opportunity to make ILS approaches as often as airline pilots of comparable years of experience, their background does make them capable of providing expert opinion to assess the relative difficulty of flying various glide slopes and flare paths.

Instrument-Flight Simulation

The rear cockpit of the airplane was fitted with a fabric hood which could be pulled forward to block exterior vision for instrument flying. A safety pilot was used in the front cockpit to take the controls when necessary.

Test Procedures

The instrument landing approaches were flown with the airplane approaching the outer marker in level flight at an altitude which would allow the pilot to push over and acquire the glide slope near the outer marker. The pilot then attempted to fly an instrument approach by using the ILS cross pointers for guidance. After several successful instrument approaches were made at a given glide slope, the angle was increased until an upper limit was reached. The glide slopes used in this investigation were 2.5°, 6°, 7°, 8°, and 9°. Pilot opinion supported by measured flight-path deviations was used to determine a maximum glide slope that seemed feasible for operational use.

Several pilots were used to obtain a comparison of the approaches made at this maximum operational glide slope with approaches made at the conventional 2.5° slope. Flare-path guidance was provided during these tests and the pilot's task was to continue the instrument approach to touchdown, if possible.

During some of the tests, the safety pilot controlled the lateral flight path to simulate a split-axis autopilot. This autopilot simulation allowed the test pilot to concentrate on the longitudinal control.

RESULTS AND DISCUSSION

Airplane Performance Characteristics

Aside from the pilot's ability to control an airplane in a steep descent under instrument-flight conditions, the steep-descent capability is ultimately limited by the airplane performance characteristics. The characteristics which are related to the descent performance of the test airplane are presented in figure 3 as a variation of thrust required with airspeed for several flight-path angles and two values of airplane weight. These curves were determined from the drag polar given in reference 4 for this airplane. The measured values of throttle position and the pilot's notes of corresponding engine rpm readings were related to the thrust-required values for several tests at various flight-path angles to give an approximate correlation between percent engine rpm and engine thrust as shown in figure 3.

For the 2.5° glide slope, the handbook gives approach speeds of 122 knots and 107 knots for airplane weights of 13 000 and 10 000 pounds, respectively.

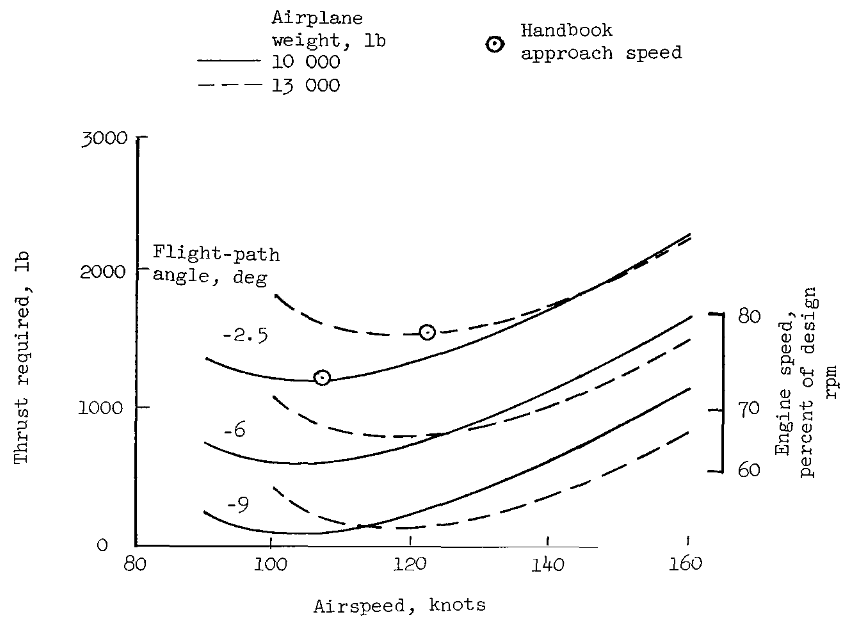


Figure 3.- Variation of thrust required with airspeed.

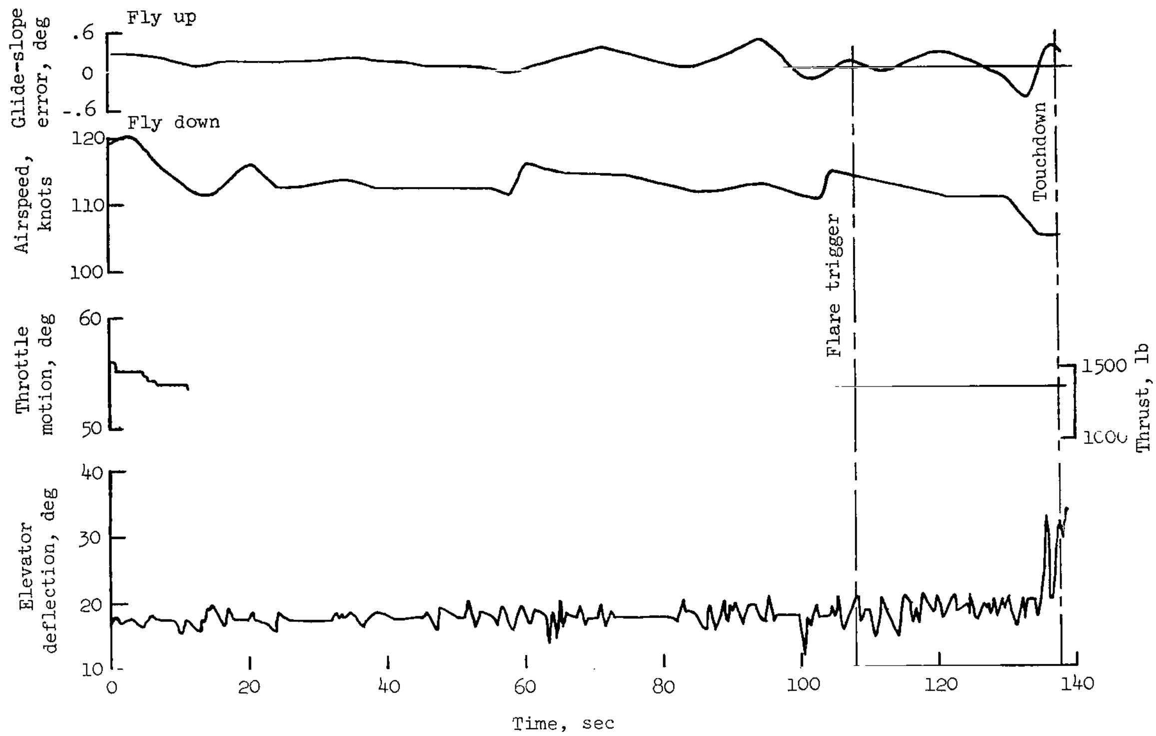
Figure 3 shows that steady unaccelerated flight along a 2.5° glide slope would require an engine speed slightly less than 80 percent of design rpm at a weight of 13 000 pounds and about 75 percent of design rpm at 10 000 pounds. Most of the tests for the 6° glide slope were made at speeds between 115 and 120 knots with engine speeds about 65 percent of design rpm.

Less than 65 percent of design engine rpm was not believed to provide adequate engine acceleration for safe wave-off characteristics. At 65 percent the airplane could be flown at glide slopes as high as 9°, but approach speeds between 145 and 156 knots resulted from the lack of sufficient drag in the approach configuration (full flaps, gear down, and speed brakes extended). Touchdowns were not made because this low drag also would cause excessive touchdown speeds on the order of 130 knots and therefore would result in landing on the nose wheel first.

Glide-Path Control for 2.5°, 6°, and 9° Glide Slopes

Because of the limited scope of this investigation, it was not possible to obtain enough data for a statistical analysis of the relative accuracy of flight-path control for various glide slopes. The primary purpose was to determine the maximum glide slope suitable for operational use and the reasons for limiting this value. Pilot opinion was used to assess the relative difficulty of flying the steep glide slopes as compared with the conventional 2.5° glide slope.

The time histories in figure 4 show the range of glide slopes investigated. The results of the tests for the intermediate 7° and 8° glide slopes were similar to those illustrated in figure 4 for the 2.5°, 6°, and 9° glide slopes.



(a) 2.5° glide slope.

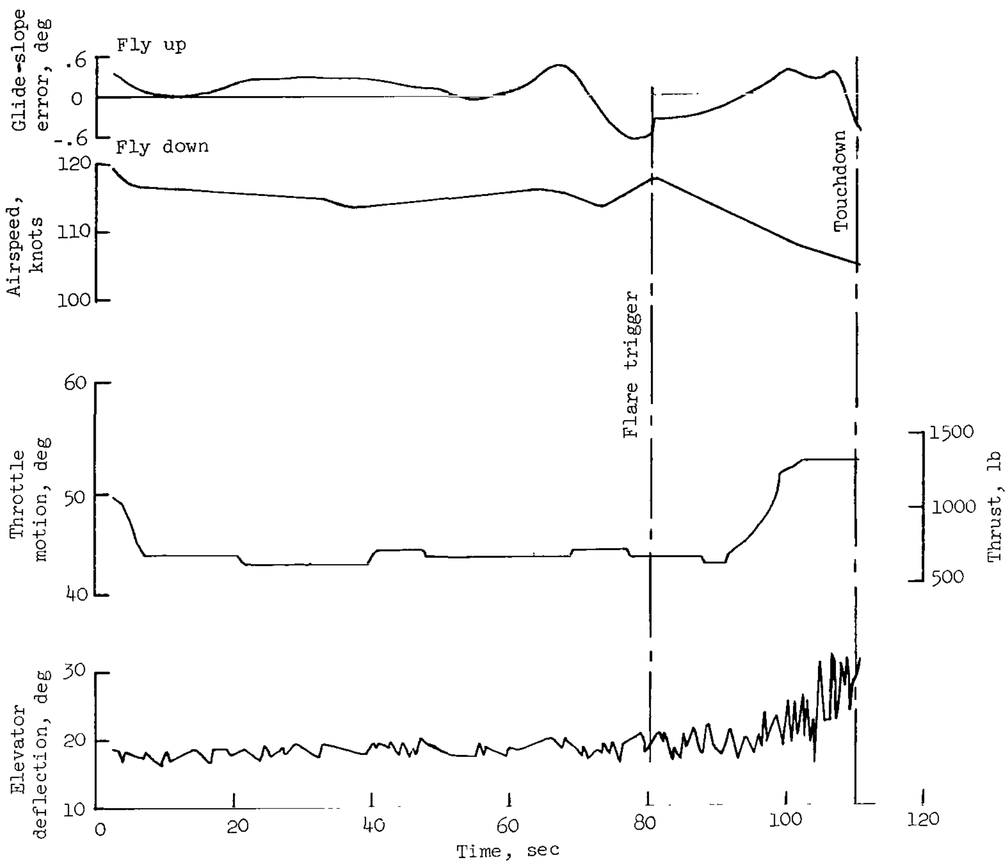
Figure 4.- Variation of glide-slope error, airspeed, throttle motion, and elevator deflection with time for three glide slopes.

The 2.5° glide slope (fig. 4(a)) illustrates a case in which the aircraft was under simulated split-axis autopilot control and the pilot was able to fly a flare path to touchdown while under the hood. The 6° glide slope (fig. 4(b)) illustrates one of the few times that the pilot was able to fly to touchdown while under the hood with the airplane under complete manual control. The airplane was also under complete manual control for the 9° glide slope (fig. 4(c)).

Although the data of figure 4 show an increase in glide-slope error with increasing glide slope at the flare trigger point, a summary of all approaches in which the pilot had complete manual control gives an average glide-slope error at the flare trigger point of 19, 11, and 19 feet for 2.5°, 6°, and 9° glide slopes, respectively.

The pilot effort required for glide-path control increases as the glide slope increases, as indicated in figure 4 by the increased frequency of elevator-control motions and increased magnitude of throttle motions for the 6° and 9° slopes compared with these values for the 2.5° slope.

For the 2.5° slope in this figure, after the airplane was stabilized on the glide slope no throttle movement was required throughout the approach and flare. The airspeed varied between 110 and 116 knots on the glide slope.



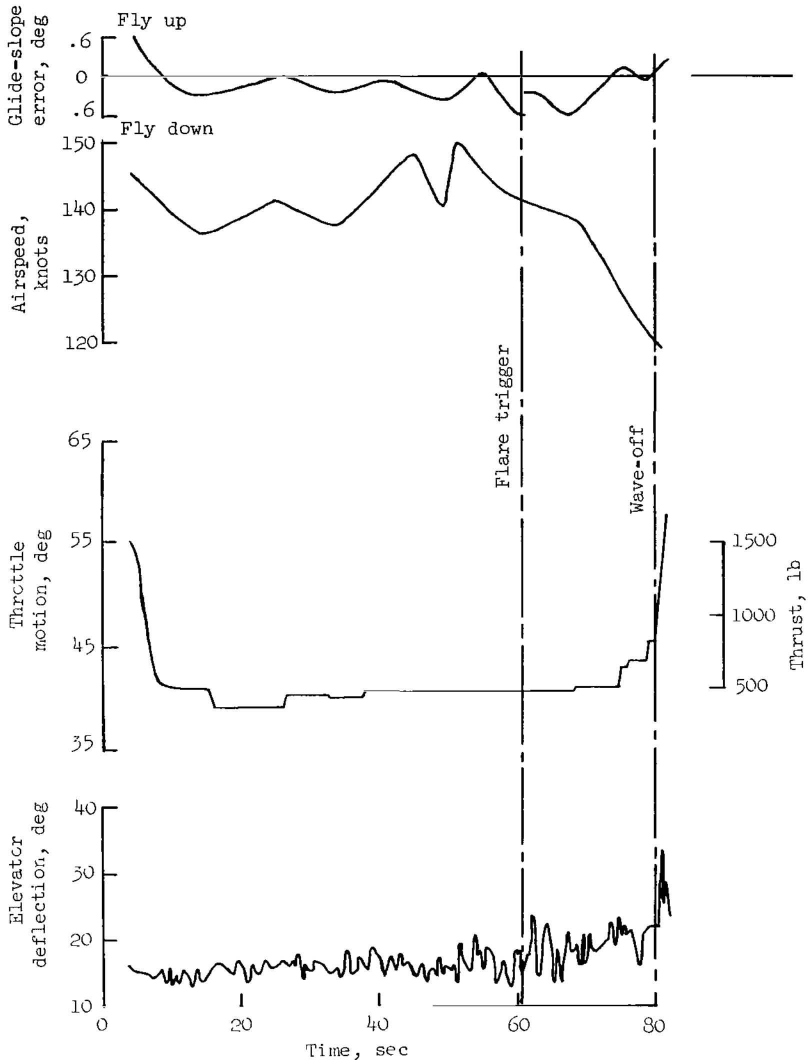
(b) 6° glide slope.

Figure 4.- Continued.

More throttle movement was required for the 6° slope in figure 4 than for the 2.5° slope. These small throttle movements varied the thrust in increments of 100 pounds or less. The airspeed was steady, varying between 113 and 118 knots.

The 6° glide slope was picked as the maximum slope suitable for operational use based on the minimum usable engine rpm and the desirable airplane landing attitude and speed. The pilots think that the 6° glide slope is more difficult to fly than the 2.5° slope partly because more attitude change occurs at the glide-slope intercept and more small power changes are required to control the speed and flight path.

After the airplane was established on the 9° glide slope, no more throttle movement was required for this slope than for the 6° slope. The large airspeed variation shown for the 9° slope during the 20 seconds before flare was probably due to a wind shear. Even at the higher approach speeds, the engine rpm for the 9° glide slopes had to be reduced to 57 percent of the design value which is much lower than 65 percent, the value considered to be the minimum for



(c) 9° glide slope.

Figure 4.- Concluded.

operational use. Although the 9° glide slope would not be suitable for operational use with this particular airplane because of low drag which results in high approach speeds, the glide slope was flown with reasonable precision in the investigation. However, the large attitude change required at the glide-slope intercept makes the glide-slope acquisition even more difficult for the 9° slope than for the 6° slope.

Lateral-Directional Control

The lateral-directional control was much better for this airplane than for the C-47 as reported in reference 2. Figure 5 gives a typical time history of localizer error and corresponding glide-slope error and airspeed for one hooded approach at a 6° glide slope. For the T-33, the error does not exhibit the oscillatory variation which was typical with the C-47. Even with the improved lateral control system, the difficulty in keeping the localizer needle centered detracted from the task of glide-slope control to the extent that hooded approaches to touchdown were possible only occasionally.

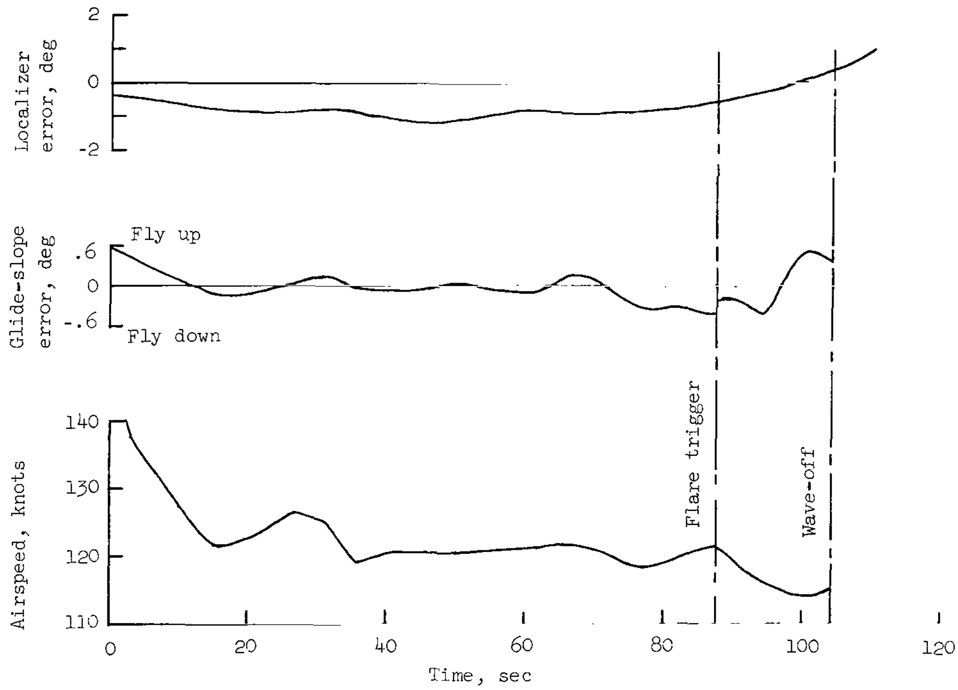


Figure 5.- Localizer error, glide-slope error, and airspeed for a hooded approach at 6° glide slope.

In the investigation of reference 2, the pilots believed that with split-axis autopilot control of the lateral-directional axes, hooded approaches to touchdown would be possible with manual control of the vertical flight path. This split-axis control was simulated during some of these tests by having the safety pilot fly the horizontal flight path visually while the hooded test pilot flew the vertical flight path. All pilots found the split-axis control to be very effective in allowing more effort to be put on the glide-path control, which resulted in consistent touchdowns with the pilot under the hood. The effectiveness of the split-axis control is shown in the following table by comparison of the number of hooded touchdowns made by three evaluation pilots having either complete control or split-axis control:

Glide slope, deg	Number of runs	Touchdowns
Complete manual control		
2.5 6	8 8	1 1
Split-axis control		
2.5 6	4 3	3 3

Flare Paths

Flare paths with lengths of 5000 feet and 6000 feet were investigated. The longer flare paths shown in figure 6 were more desirable for the steeper glide slopes because there was more time to make the large flight-path change required from the steep slopes to the small terminal angle. For example, at an average ground speed of 115 knots, the airplane could traverse the 5000-foot flare path in about 26 seconds; but the 6000-foot flare path would require 31 seconds. These lengths for flare paths may seem unusually large, but the flare paths are flown manually by hooded pilots to touchdown. One of the pilots commented that the time required for transition from the 6° glide slope to the 0.5° terminal angle was too short. (In this instance, the time from start of flare to touchdown was 25 seconds.)

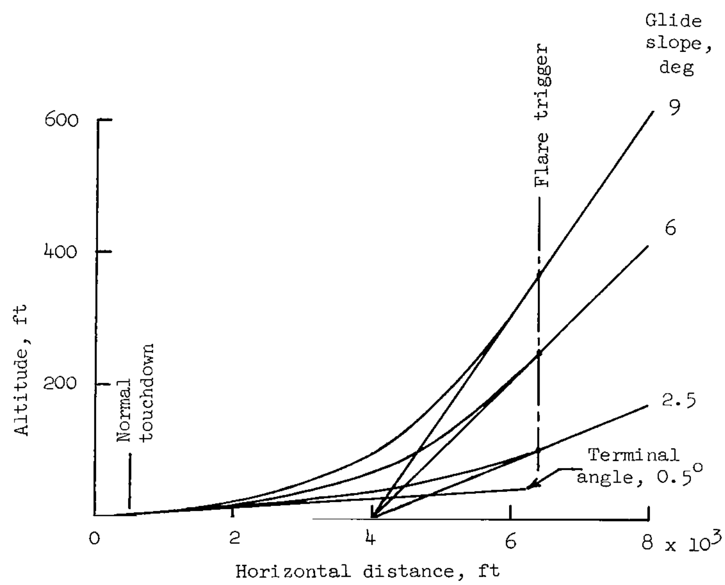


Figure 6.- Flare paths for several glide slopes.

The 6000-foot flare path was flown with the 9° glide slope but was not fully evaluated because the tests had to be discontinued before touchdown. Touchdown was prohibited by a nose-down attitude which resulted from higher speeds encountered with the 9° glide slope.

For the flare from the 2.5° glide slope (fig. 4(a)), the airspeed dropped from 114 to 104 knots with no addition of thrust. The airspeed dropped from 118 to 105 knots during the flare from the 6° glide slope even with the addition of a considerable amount of thrust (fig. 4(b)). During the flare from the 9° glide slope (fig. 4(c)), the airspeed dropped from 141 knots to 120 knots at which time a wave-off was initiated. The larger attitude changes required in the flare from the steep glide slopes demand more effort by the pilot to maintain the airspeed during the flare. If the steep approaches are to be continued through the flare to touchdown, or to very low altitudes, some form of automatic speed control in addition to the necessary split-axis autopilot would be very desirable.

Flight Instrument Requirements

Some of the pilots' comments concerning the flight instruments used during this investigation are worthy of consideration.

The proper grouping of instruments is often overlooked, as in the present case. A photograph of the instrument panel used in this investigation is shown in figure 7. This grouping increased the pilot's effort required in scanning his instruments during an ILS approach, primarily because the cross-pointer indicator is separated from the other instruments needed for flight-path control (rate-of-climb, heading, and airspeed indicators, and attitude gyro).

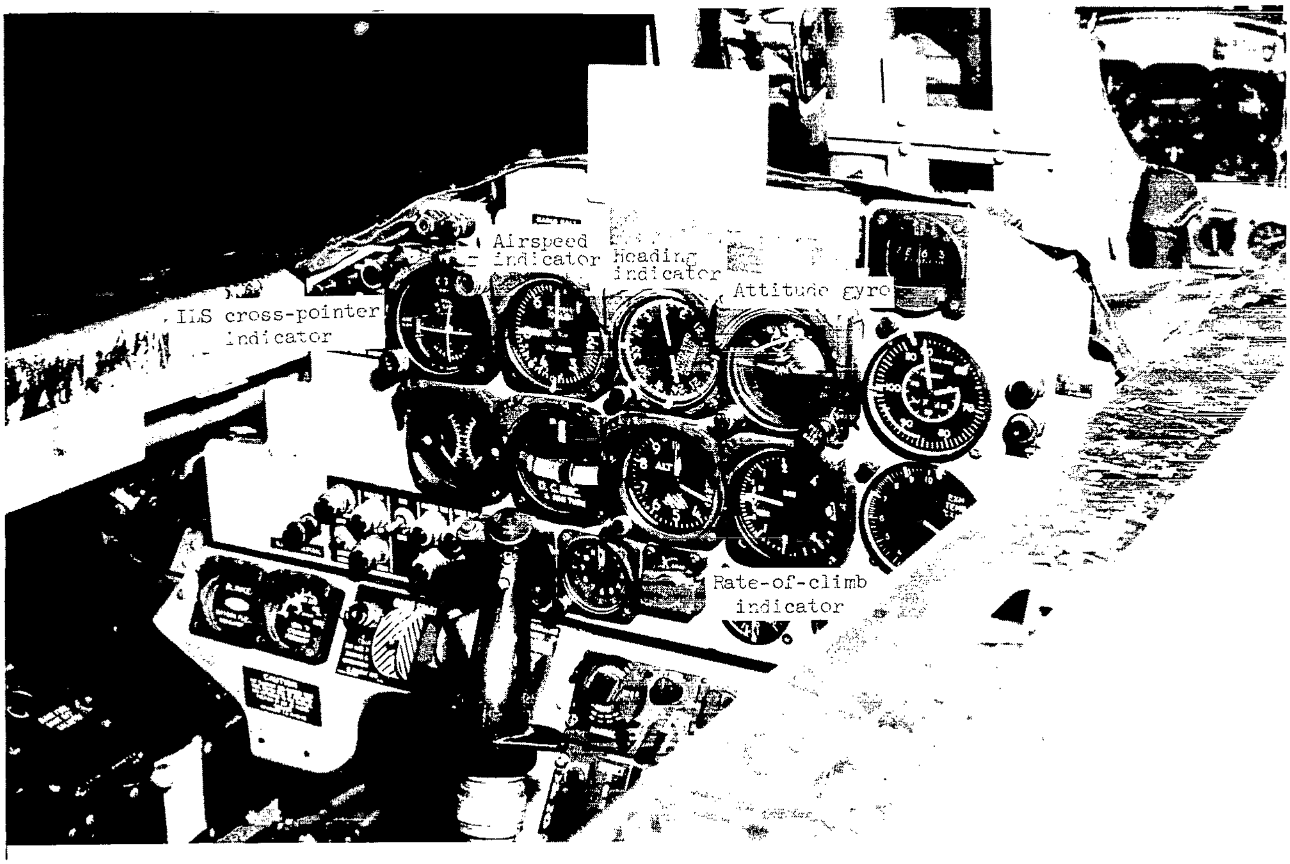


Figure 7.- Instrument panel. L-63-5490.1

CONCLUDING REMARKS

A flight investigation has been conducted to determine the steep instrument approach capabilities and limitations of a T-33 airplane under manual control. The study included an investigation of flare paths suitable for transition from the steep glide slope to touchdown.

The maximum glide slope feasible for operational use in an instrument approach was 6°. This limit was established by the desired approach speed and the minimum engine speed that could be used. The minimum engine speed was chosen as the lowest speed which would still respond adequately if a wave-off occurred.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., January 12, 1965.

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